APPLICATION OF SOFT COMPUTING TECHNIQUES TO MICROWAVE AND MILLIMETER WAVE DOMAIN

A

Synopsis

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1. Introduction

Form the decade to a decade's distinct advancements in the microwave technology is observed. Microwave is the electromagnetic spectrum which has a frequency range of 300 MHz to 300 GHz, and wavelength of 1m to 1mm. Microwave components are the main wheel of the communication system. Currently in India, subscription number is increasing rapidly day by day. The microwave technology is used widely because of its versatile range of applications, like wireless communication, satellite and spacecraft communication, medical field, remote sensing, radar, electronic warfare, consumer appliances (Bahl & Bhartia, 1980; James, Hall, & Wood, 1981). Microwave technology is highly in demand because of its properties such as simplicity, low manufacturing cost, lightweight, low profile, reproducibility, reliability, and ease in fabrication and integration (Garg, Bhartia, Bahl, & Ittipiboon, 2001).

Microwave include Millimeter-wave which has an extremely high frequency (EHF), their electro- magnetic spectrum started from 30GHz to 300GHz and having wavelength 1 cm to 1 mm. It provides uninterrupted real-time communication between people and billions of smart devices in daily life. Millimeter-wave (or mm-Wave) communication systems have emerged as a key wireless technology for fifth-generation mobile network and beyond, as well as for high-speed wireless local area networks (WLANs), due to its wide spectrum bandwidth (Rangan, Rappaport, & Erkip, 2014). This technology has recently drawn considerable attention because of the increasing explosion of mobile traffic (Rappa- port et al., 2013). The first millimeter-wave, electromagnetic waves at 60GHz, over 23 meters ranges were examined by the Indian scientist Jagdish Chandra Bose in 1890, in Presidency College, Calcutta, India. Jagdish Chandra Bose became a first scientist who developed these millimeter-wave components such as spark transmitter, coherer, dielectric lens, polarizer, horn antenna, and cylindrical diffraction grating (Bose, 1998). This is the first millimeter-wave communication system in the world, developed over 100 years ago. But for the more large-scale bandwidth and the new beamforming technology demand the significant design, prototype, and testing challenges.

For more advancement in this area there is a need for more analysis and different microwave designs that can enhance the performance of the microwave component. As per the demands of the

consumers, researchers and industries opted soft computing technique over traditional methods for analyzing and designing of microwave components. One of the problems in traditional control systems is that com- plex plants cannot be accurately described by mathematical models and are therefore difficult to control using such existing methods. On the other hand, soft computing deals with partial truth, uncertainty and approximation to solve complex problems. "The guiding principle of soft computing is to explore the tolerance for imprecision, uncertainty, and partial truth to achieve tractability, robustness, low solution cost, a better rapport with reality" is quoted by Dr. Zadeh, who initiate the fuzzy logic (Zadeh, 1992; Ibrahim, 2016). Soft computing methods play a crucial role in modeling and optimization of the microwave devices (Liu, Na, Zhu, Ma, & Zhang, 2017). Artificial neural networks (ANN), Evolutionary computing, and Fuzzy logic are part of soft computing, that provides accurate and fast results of microwave components. Soft computing is a functional key, which mimics the human brain like a human study of sense, thought process, analysis and the science of discovering the actual relationship (Dahiya, n.d.), which is a combination of natural as well as the artificial process. Soft computing built a conceptual intelligence in machines and solves complex problems, a system of computing includes Neural network, Fuzzy logic, and Genetic algorithm. Electromagnetic (EM) design optimization is ex- pensive due to the requirement of repetitive EM simulations because of the adjustments of geometrical parameters. ANNs can establish the relationship between EM responses and geometrical parameters of the training process (Feng, Zhang, Ma, & Zhang, 2015).

A neural network trained to model original EM problems can be called the forward model where the model inputs are physical or geometrical parameters and outputs are electrical parameters. For designing purposes, in order to find the geometrical/physical parameters for given values of electrical parameters, the information is often processed in the reverse direction which is called the inverse problem. There are two methods to solve the inverse problem, i.e., the optimization method and direct inverse modelling method. In the optimization method, the EM simulator or the forward model is evaluated repetitively in order to find the optimal solutions of the geometrical parameters that can lead to a good match between modelled and specified electrical parameters. This method of inverse modelling is also known as the synthesis method. The formula for the inverse problem, i.e.,

compute the geometrical parameters from given electrical parameters, is difficult to find analytically. Therefore, the neural network becomes a logical choice since it can be trained to learn from the data of the inverse problem. We define the input neurons of a neural network to be the electrical parameters of the modelling problem and the output neurons as the geometrical parameters. Training data for the neural network inverse model can be obtained simply by swapping the input and output data used to train the forward model. This method is called the direct inverse modelling. Once training is completed, the direct inverse model can provide inverse solutions immediately unlike the optimization method where repetitive forward model evaluations are required. Therefore, the direct inverse model is faster than the optimization method using either the EM or the neural network forward model (Kabir, Wang, Yu, & Zhang, 2008).

2. Review of Literature

Although, vast literature is available on the analysis and designing methods of microwave and millimeter wave components using soft computing, but we are focusing on ANNs and Genetic algorithm- based methods. Given below is a review of some important reports published.

Chao Zhang et al (2018) (C. Zhang, Jin, Na, Zhang, & Yu, 2018) have reported the non-uniqueness problem which can be managed very well by multivalued neural network inverse modeling techniques. The proposed work takes input as an electrical parameter and output come in the geometrical or physical parameter. The analytical approach of inverse modeling can't build a relationship between input and output, but by using proposed model it can be done because it trained the model to learn inverse modeling data, the multi-value neural network can learn all training data automatically and redirecting conflicting information to different values of the proposed inverse model. Therefore, this technique can solve the problem of non-compliance in a simpler and more automated manner.

Wei Zhang et al. (2018) (W. Zhang et al., 2018) discussed a proposed method used for tunable four-pole waveguide filter at 10.5-11.5GHz and iris coupled microwave cavity filter at 690-720MHz. Space- mapped Multiphysics parametric modeling technique to create high-grade microwave components. In this method, they use the relationship between EM single physics and different values of geometrical parameters of microwave components as the coarse model. The coarse model is trained by Artificial neural networks or neuro-transfer function techniques. The outcomes are very good at

accuracy and less computational cost with smaller Multiphysics training data.

Claudio Fiandrino et al. (2019) (Fiandrino, Assasa, Casari, & Widmer, 2019) addressed the challenges arises in the mm-wave communications, like higher propagation loss, atmospheric absorption also penetration loss. For this, they perform an efficient in-band mm-wave location system that will allow the future mm-wave network to adapt faster to changing environmental circumstances and scale to high device densities.

Feng Feng et al. (2016) (Feng et al., 2015) proposed a method which is the combined form of neural network and Pole-Residue based transfer function for parametric modeling of EM behavior of microwave components which is more fast, accurate and reliable over direct EM optimization. They also calculate the experimental time of the Microwave Junction, Ultra-wideband Antenna and Coupled-line filter of microwave components with their proposed work and the direct EM optimization.

Table I

Microwave Components	**Direct EM optimization** (Time)	**Optimization Using Pole-Residue Neuro-TF model** (Time)
Microwave Junction	7.7 hours	0.72 hours
Ultra-Wideband Antenna	35.2 hours	3.92 hours
Coupled-line filter	22.7 hours	1.95 ours

Jiexi Yin et al. (2019) (Yin, Wu, Yu, Wang, & Hong, 2019) the proposed method is the winning method for mm-wave applications, which get the total efficiency more than 85% and impedance band- width 45.4% is obtained. A low-profile antenna with having one longitudinal slot with both TM10 and TM20 mode successfully excited and two transverse slots in it, and also unique symmetries E-shaped pattern is showed by transverse slots. The proposed antenna results are good in terms of impedance bandwidth, complexity, cost, and radiation efficiency. The proposed path antenna is designed, built and measured around the Ka-band.

M.F. Jimenez Nogales et al. (2008) (Nogales, Garcia, Hinojosa, & Melcon, 2008) focused on accurate fitness functions based on sigmoidal functions give a more accurate and fast solution of the Ku-band rectangular waveguide band pass filter for satellite applications. The GA-based optimization

technique was successfully used in the project bipolar pass of the rectangular iris band in the Ku band. Different fitness functions are studied, suitable optimization of the filter has been proposed. They are used to measure the degree of fulfillment based on discrete or continuous target specifications.

Qi- Jun Zhang et al. (2003) (Q.-J. Zhang, Gupta, & Devabhaktuni, 2003) communicated the paper on building a technical bridge between microwave design concepts and neural network fundamentals. Recently Neural network gained recognition as its remarkable features like the fast, accurate and flexible tool to RF/ microwave modeling, simulation, and design. The neural network is trained to learn the behavior of passive/ active components circuits. A quick and accurate response to the task easily learned. Neural networks are an interesting alternative to these traditional methods. Trained neural networks can be used for high-level designing, as a numerical modeling method are costly and difficult to obtain. Author's aim of this paper is to promote university research into practical applications.

J. Francisco et al. (1999) (Ares-Pena, Rodriguez-Gonzalez, Villanueva-Lopez, & Rengarajan, 1999) experimentally defined the application of genetic algorithms (GA's) in array pattern synthesis. They applied genetic algorithms (GA's) for solving three important problems related to the synthesis of antenna array patterns. Firstly, they built the fast convergence of this method in search of the optimal solution from a very large solution space for a consistently null-filled linear array. Then there comes to search for the optimal null-filling topography for the radiation pattern of a linear array. And finally, a hybrid method is explained for array thinning by joining GA's and simulated annealing (SA), which is effective in removing unwanted elements from a planar array.

P. Burrascano et al. (1998) (Burrascano, Fiori, & Mongiardo, 1999) have provided a brief idea of neural network applications of microwave CAD; also the problems arise during practical implementation. Self-organizing mapping enhancing model accuracy and applicability, further refinement of neural modeling pre-grouping accuracy answers through self-organizing maps, it also looks promising. This program represents the overall modeling task divided into several separate modeling processes the output comes with higher accuracy without implying an unacceptable

increase in the computational cost associated with the training phase.

3. Motivation

The growing commercial market of Microwave/ Millimeter wave industry over the past decade has led to the explosion of interests and opportunities for the design and development of microwave components. Particularly, for the communications industry, the onus is on the successful development of components in shortest possible time with optimized cost. There is also a class of critical design applications such as design of high-power devices and components where the accuracy requirement is the prime goal. The design of the most microwave components requires the use of commercially available electromagnetic (EM) simulation tools for their analysis. In the design process, the simulations are carried out by varying the design parameters until the desired response is obtained. The optimization of design parameters by manual searching is a cumbersome and time-consuming process, and the chances to get local minima are very high.

The mathematical calculations and mathematical methods or in short, the traditional methods were so complex, time-consuming and need more resources which makes them an inappropriate choice to be used. There are certain limitations using traditional methods in the present scenario. We are focusing on fast, accurate, robust and efficient designing methods; soft computing is the great choice for that. There is prime importance of accuracy and efficiency in techniques of design in microwaves and millimeter waves integrated systems. As per the increasing demand of lightweight and small microwave systems and subsystems for the communication industry, and also in the defense sectors the complexity of the circuits is increasing day by day and it leads to a high-density system with a large number of interconnects. These fast and advance methods are capable of controlling multiple variables together. The recent progress in terms of precision and effectiveness of soft-computing techniques based on fuzzy logic, neural networks and genetic algorithms for designing microwave devices motivates me to research in this area. There are many advantages of using soft-computing algorithms in engineering optimizations. First, they are derivative free methods for design optimizations. Second, they can handle many variables simultaneously. Third, they can be interfaced with various EM simulation tools. Recently nonlinear neural optimization networks have been used for

the analysis of micro-strip patch antennas (Vegni & Toscano, 1997). To accurately characterize the devices as per the interest the methods based on electromagnetic theories have been used, but they require higher computational resources and time, which makes it a rather inappropriate choice to be used in microwave CAD (Gupta, 1998, Zhang and Gupta, 2000). On the other hand, soft-computing is a consortium of methodologies which work synergetically and provides flexible information processing capabilities for handling real life ambiguous situations in various forms.

Soft-computing techniques have many advantages in solving engineering optimization problems. These techniques are capable of handling multiple variables simultaneously. Due to the recent successes in terms of accuracy and efficiency of soft-computing techniques for the design of micro-strip devices like procedures based on neural net- works and genetic algorithms. We are motivated to carry research in the area of design of microwave components using soft-computing and to explore the possibility for new design procedures based on soft computing which have accuracy and efficiency. The proposed work is presented in following section with the specific objectives of proposed research work.

4. Objectives

As already mentioned in the introduction the traditional or conventional techniques of solving the design problem and analysis of the different types of microwave components like filters, resonator, antenna, etc. are very complex. These methods required a lot of resource over its new soft computing methods are easy for handling this kind of situation. So, to deal with aforementioned situation following specific objective has been proposed:

1. To explore fast and effective procedures based on soft computing to analyze and design microwave components.
2. To solve inverse modeling problem of microwave and millimeter wave microstrip devices using soft computing.
3. To develop models to solve multivalued problem in microwave microstrip device design.
4. To fabricate designed microwave components.
5. To compare measured experimental and theoretical results to validate proposed models and

approaches.

5. Methods of Soft Computing

The brief summary of two different soft computing methods, i.e. Artificial Neural Network and Evolutionary computing is given below:

5.1 Artificial Neural Network

Artificial neural networks (ANNs) are based on the information processing which is similar to the processing of our biological nervous system (Choudhury, Bisoyi, & Jha, 2012). ANNs system motivated by the way human brain sense, thought process, analysis and science of discovering the actual relationship (Dahiya, n.d.). In the nervous system, neurons carry information through the nerve cells through an electrochemical process. But the artificial neural network uses the artificial neurons to carry information.

Each connection link between layers is associated with a weight, which controls the behavior of trained ANNs. True nodes are bind in very complex ways, including both feed-forward and feedback connections. ANNs only work with the feed-forward connections to carry information, which are easier to handle it. Generally, ANNs used in many application like stock market prediction, date recognition, weather prediction, pattern recognition, image compression, and security (Ibrahim, 2016). The objective of neural networks is to solve real-life problems in a smarter way with high accuracy and faster way over traditional techniques. Many neural networks are applied "Back-propagation algorithm" is used to train the networks. ANNs is basically composed of three layers such as input layer, hidden layer, and output layer. The neurons give the input to the system then passes the information for the processing to the hidden layer and if the output is not close to the desired output then it again modified the weights till the error become less and value is closed to the desired output. After examining neural network structures and training methods, they provided a general process for the development of accurate and efficient electromagnetically-trained neuron network (EMNN) models for microwave computer-aided design (CAD). There are many other methods also to train neural network like forwarding model and inverse modeling methods (Choudhury et al., 2012). They presented neural network modeling for various RF and microwave

components such as transmission line structures, active devices, microwave circuits, antennas, and systems.

5.2 Evolutionary Computing

Evolutionary computing is also known as genetic algorithm. It is an optimization and computer-based search methodology that uses computational models of evolutionary process such as natural selection, reproduction and survival of the fittest. This method is very effective in finding optimal solution to a wide variety of problems (Fogel & Computation, 1995). Genetic Algorithm (GA) was introduced by John Holland in 1975, with the purpose to understand the selection process of natural systems and to design artificial system software to retain the strength of natural system. Artificial intelligence and uncertain computing include genetic algorithm (Holland et al., 1992), which are mainly used to find the solutions of the various optimization problems in real-life applications.

To bring evolution in computing, a genetic algorithm is introduced which is basically a model of machine learning. The working principle of Genetic algorithm is based on four steps, which include selection, evaluation, crossover and mutation as shown in figure1. The successive GA operations, such as selection (the candidates from one generation are selected for the next generation), crossover (genetic material of one candidate is exchanged with another candidate) and mutation (genetic material of one candidate is altered), are repeated to the population until to obtain a chromosome with the desired fitness. (Nogales et al., 2008).

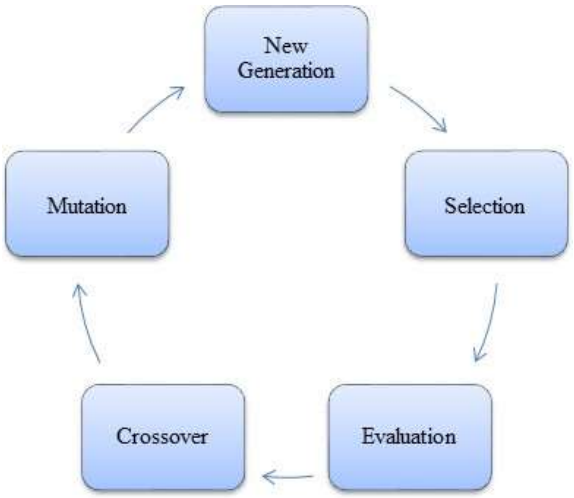

Figure 1: Flow chart showing the process of GA

The method of Genetic Algorithm can be used in engineering applications for finding solutions to complex search problems. Large impedance frequency selective surface (FSS) (Kern & Werner, 2003), artificial magnetic conductor (AMC) surfaces and the electromagnetic band-gap (EBG) structures (Liang, Li, Bossard, Werner, & Mayer, 2005) are being used in mathematical absorber design and analysis. However, soft computing is an efficient way for design purpose and optimization of complex structures. Genetic algorithm is also applicable in a wide range of fields like automatic manufacturing and design, electronic design, games theory, control engineering, code-breaking, biomedical engineering, and climatology. There is a difference between the normal search algorithms and genetic algorithms such as in genetic algorithm coding of parameters is used and not parameters themselves. Unlike normal search algorithms, the genetic algorithm searches through a population of points. It doesn't use derivatives but it uses objective functions and the rules-based on probability.

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